UCRL-CONF-203610

LAWRENCE LIVERMORE NATIONAL LABORATORY

Target Diagnostic Technology Research & Development for the LLNL ICF and HED Program

P.M. Bell, C.V. Bennett, J.R. Kimbrough, O.L. Landen, J.W. McDonald, H-S. Park, F.A. Weber, J.D. Moody, M.E. Lowry, J.P. Holder, R.A. Lerche, Terence Davies

April 16, 2004

15 Topical Conference on High Temperature Plasma Diagnostics
San Diego, CA, United States
April 19, 2004 through April 22, 2004

Disclaimer

TARGET DIAGNOSTIC TECHNOLOGY RESEARCH & DEVELOPMENT FOR THE LLNL ICF AND HED PROGRAM

P.M. Bell, O. L. Landen, F. A. Weber, M. E. Lowry, C. V. Bennett, J. R. Kimbrough,

J. D. Moody, J. P. Holder, R. A. Lerche, R. L. Griffith, H. S. Park, * R. Boni, * P. A. Jaanimagi, # T. Davies

Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94551, USA

**Laboratory for Laser Energetics, University of Rochester,Rochester, New York 14623-1299*

 # Bechtel Nevada, Special Technologies Laboratory, Santa Barbara,CA 94551

Abstract

The National Ignition Facility is operational at LLNL. The ICF and HED programs at LLNL have formed diagnostic research and development groups to institute improvements outside the charter of core diagnostics. We will present data from instrumentation being developed. A major portion of our work is improvements to detectors and readout systems. We have efforts related to CCD device development. Work has been done in collaboration with the University of Arizona to back thin a large format CCD device. We have developed in collaboration with a commercial vendor a large format, compact CCD system. We have coupled large format CCD systems to our optical and x-ray streak cameras leading to improvements in resolution and dynamic range. We will discuss gate-width and uniformity improvements to MCP-based framing cameras. We will present data from single shot data link work and discuss technology aimed at improvements of dynamic range for high-speed transient measurements from remote locations

I. Introduction

Experiments conducted at the National Ignition Facility (NIF) require improvements to current instrumentation technology. Our work has focused in the area of two dimensional readout systems, streak camera systems, data transmission, optical calibration systems and x-ray framing cameras. Work described has been incorporated or will be integrated into diagnostic systems at NIF. Some of the systems described are deployed on instrumentation at the facility.

II. OPTICAL STREAK CAMERA SYSTEMS

The ICF/HED programs at Livermore have a need for a large inventory of optical streak cameras. These systems will be utilized in many diagnostic systems on NIF and other facilities. In February of 2002 a system design requirements (SDR) document was finalized, and peer reviewed.[1] This document gives the detail requirements for these optical streak camera systems. The requirements are similar to those of other streak camera systems with the exception that there is a need for better spatial resolution than available in commercial camera systems. This instrument will include remote monitoring, remote control, dry run capability, and modern components to increase functionality and reliability.

We have spent several years evaluating components and commercial optical streak camera systems to meet the system design requirements. In this investigation we found that none of the commercial camera systems would meet all the system design requirements simultaneously. There are two areas the commercial cameras we have evaluated can't meet the NIF specification. The number of resolution elements in the special direction and the dynamic range. The commercial off the shelf parts (COTS) that we evaluated will meet the streak camera requirement; there is no commercialization of them into camera systems. Figure 1 shows the contrast transfer ratio of the Photonis P510 tube coupled to an E2V 2k x 2k back thinned CCD device, readout by a Spectral Instruments Series 800 camera system. With this contrast transfer function we measure and the field of view; we can meet the required 480-resolution element requirement for the NIF optical streak camera system. Over the last year we have worked with the LLE to design, build and test a compact system based on LLE original design[2]. This new system meets the NIF SDR for the optical streak cameras. A first article streak camera was tested and the results are published in a companion paper in this proceeding[3]. Over the next year LLNL and Laboratory for Laser Energetics (LLE) will be working to complete the input optics module and automated calibration system. When the integrated system (streak tube and readout, Input optics and calibration unit) is complete this optical streak camera system will be like operating a modern oscilloscope.

III. Framing cameras

The ICF/HED programs at LLNL have for many years pursued work on ultra-high speed single line of sight framing cameras. Work on a vacuum tube version of this concept has matured to a useable device. It works by splitting the electron beam at the Fourier plane in the image tube much like a beam splitter in an optical system.[4] A companion paper describes the detail of the improvement from last reporting on this device.[5]

An additional single line of sight device is being developed under contract by MIT Lincoln labs. It is a follow on project from earlier work at LANL for the DAHRT[6] project in which they use a CMOS device with super pixels. Each super pixel is comprised of 4 smaller pixels. Each smaller pixel is gated at a different time relative to the event of interest. Our work focuses on improving the integration time from 50ns to 0.1ns – 1ns. We are also developing a new x-ray framing camera detection technique based on optical measurement of the effects of x-ray absorption and electron hole pair creation in a direct band-gap semiconductor. The electron-hole pairs create a frequency dependent shift in optical refractive index and absorption. This is sensed by simultaneously directing an optical probe beam through the same volume of semiconducting medium that has experienced an x ray induced modulation in the electron-hole population. If the wavelength of the optical probe beam is close to the semiconductor band-edge, the optical probe will be modulated significantly in phase and amplitude.

We have successfully demonstrated[7] the viability of this approach for x-ray detection in the 10keV regime. Our results thus far indicate that the technique should be capable of nearly single x ray photon sensitivity while having excellent (sub-picosecond) temporal response. A companion in these proceedings presents a progress report on our development of imaging pixels with this optical-based x-ray detection technique.

IV. Two-dimensional readout systems

The ICF and HED programs at LLNL have utilized film as the media of choice for recording the output of framing cameras[8] and x-ray streak cameras[9] for many applications. Many of these systems are built utilizing 40mm image intensifier tubes. Typical outputs utilized 35mm rolled or 100mm by 125mm film plates of Kodak 2484 or TMAX 3200 film. Systems that utilized CCD's were limited. The goal of this work is to replace film based systems with electronic readouts in all possible instrumentation on the NIF. We have broken the readout problem into two parts: the sensors and the electronics to support the sensors.

The CCD sensors need to cover three major wavelengths or energies: 400nm-680nm (optical), 100eV-100keV (x-ray) and 3keV-13keV (electron) recording. Optical recording for our applications is typically to record the output of phosphor screens. Electron recording is for streak and framing camera applications. The spectral coverage requirements for x-rays are broad, from vacuum ultraviolet to x-ray energies similar to those used for medical application. Several criteria were used to choose a suitable device for meeting these applications.

The devices had to be capable of direct one to one coupling of a typical 35^2mm output, a pixel size in the range of 15 µm, be readily available and reasonably priced. There are few selections for such devices at reasonable cost. The sensor we have based our development around is the Kodak KAF 16800(4k x 4k, 9µm pixel) 36.88^2mm family of devices.

Under contract and in collaboration with the University of Arizona[10] we have back-thinned devices obtained from Kodak[11] to improve their sensitivity for all applications. The devices were purchased in wafer form to allow for handling and processing. The devices are packaged to be pin for pin compatible with standard front illuminated Kodak 16800-product family. Each application requires specific backside processing to enhance device quantum efficiency. We have devices that are interchangeable and are operated by a common electronics system.

Our work related to optical wavelength enhancement of the KAF 16800 is to increase the open area ratio of the device and provide improved AR coatings at fiber-optic and phosphor screen interfaces. Typical front-side illuminated sensors that we have utilized have quantum efficiencies that range from 15% to 40% depending on the wavelength of operation and gate structures on the device. Figure 2 shows the quantum efficiency the optically enhanced device of 75% at 540nm. All of the devices built to date exhibit charge transfer efficiencies typical of scientific grade devices (.999998). The next step in this area of work is to bond a device to a large fiber bundle and measure the quantum efficiency of the bonded devices.

Two devices were fabricated for use as soft x-ray detectors. The passivation of the backside surface is the critical process that allows for enhanced Qe to low energy x-rays. Through careful work we have optimized the passivation mechanism to reduce absorption of soft x-rays (<1keV). Figure 3 shows the quantum efficiency of the x –ray device from 200ev to 6keV x-rays. The high-end cutoff is due to the finite silicon thickness of ~10μm.

Fe-55 analysis yielded horizontal clock transfer efficiency of 0.999996 and vertical clock transfer efficiency of 0.999998, with a read noise of 6.9 electrons at a system gain of 0.6 electrons per analog digital unit (e/ADU) and a rate of 40 kHz. At 0.5 MHz, the chip was read at gain of 0.6 e/ADU with read noise of ~ 9 electrons, and at 1 MHz the system gain was 2 with read noise of ~11 electrons. At an operating temperature of -40 deg C, the dark current was measured below 0.02 electrons/pixel/second.

The device can also be utilized as an electron sensitive detector. 10-15keV electrons have a shallow penetration range (< 2μm). Figure 4 is the output of modeling that demonstrates the electron range and the distribution within the silicon matrix.

However, the device as built creates an excessive number of electron-hole pairs in the CCD per incident 10- 15keV accelerated photoelectron, reducing dynamic range. We have demonstrated by applying a ~1000 Å layer of aluminum we can reduce the photoelectron energy deposited within the field region of the CCD, enhancing dynamic range. An additional benefit from the aluminum layer is the device becomes solar blind hence light tight filtering is not required. This device is well matched to our streak camera applications.

The Kodak device previously described will not cover the x-ray applications above 5keV with good quantum efficiencies as shown in figure 2. Work this past year was started to develop imaging sensors with better sensitivity to x-rays in the 6keV – 100keV range. Figure 5 shows the sensitivities of each of the fundamental materials we have used for devices. Three approaches are being pursued including CdTe pixilated devices, fully depleted thick CCD devices and

CCD's with scintillators. The CdTe device is a commercial system built by Ajat Oy Ltd of Finland. The fully depleted device was built by Lawrence Berkley Labs[12] as an Infrared detector. The device is 300 micron thick silicon, making it very useful for high-energy x-ray application. We will complete testing over the next year on this device. The final detector system is a large area scintillator grown on a fiber faceplate that is then bonded to a backthinned E2V larger format CCD. This detection system is optimized for low and mid band x-rays. Work from the CdTe and CCD with scintillators is described in two companion papers in this proceeding.[13]

V. Model SI1000 CCD camera

Under an LLNL contract with Spectral Instruments[14] we have developed a compact network addressable scientific grade CCD electronics support system. Figure 6 shows the system including the camera head with Kodak CCD, controller and power supply. In order to maximize the use of the controller an analog and digital input/output option in the camera controller permits control of both the camera head and other diagnostic functions via a single Ethernet link. The Series 1000 camera design is based on Spectral Instruments Series 800 camera. A PC104+ controller and the DC power supply have been added. Communication between the controller and the NIF network is by the fiber optic Ethernet and the link between the controller and camera head is also via fiber optic. This configuration should reduce electromagnetic pulse and electromagnetic interference problems. A companion paper detailing the performance of this system is presented in these proceedings[15].

VII. ANALOG DATA LINKS

The National Ignition Facility at Lawrence Livermore National Laboratory requires high-bandwidth and high-dynamic range data transmission of diode signals from the target chamber area to diagnostic recording equipment at a distance of approximately 150 feet. The diode signals have both high and low frequency components to them, making it very import to have a system that can handle broadband signals from 10mhz to several GHz without distortion. Figure 7 shows a step response demonstrating the use of a customized fiber optic link couple to a SCD5000 analog digitizer. In a companion[16] we descried the results of an evaluation of both commercial fiber-optic analog data links and custom links made from COTS components.

The systems need to pass short pulse signals with high fidelity, requiring a broad bandwidth frequency response that is flat in amplitude and has a linear phase response over ten's of ns. We have found that none of the commercial system tested would meet our needs. The system built by combining the best parts from various systems gave us the best results.

Acknowledgments

"The authors gratefully acknowledge the effort and support of Michael Lesser form the University of Arizona Imaging Technology Laboratory."

* This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

[1] LLNL NIF document, System design requirements, Optical Streaked Detector, NIF-0076560
[2] Donaldson W. R. et al., Rev. Sci Instrum. 73 (2606) July 2002
[3] Lerche R.A. et al., Rev. Sci Instrum. Optical streak camera performance (Poster E42)
[4] Bradley, D.K. et al., Rev. Sci Instrum. 72 (694) Jan. 2001
[5] Bradley, D.K. et al., Rev Sci Instrum. Progress on the Development of a Single Line of Sight X-ray Framing Camera (Poster E48)
[6] Reich R.K. et. al. Rev. Sci. Instrum. vol.74, no.3, March 2003, pp.2027-31.
[7] M.E. Lowry, *et. al*., *RadSensor: Xray Detection by Direct Modulation of an Optical Probe Beam*, to be published in SPIE Vol. 5194.
[8] Budil K.S. et al., Rev. Sci. Instrum. 67 (485), Feb 1996
[9] Kalantar D.S. et al., Proc. SPIE 2869, 680 (1996)
[10] University of Arizona, Mike Lesser, Ph.D. Imaging Technology Laboratory; Tucson, Arizona 85721
[11] Kodak Image Sensor www.kodak.com/go/imagers
[12] Bebek C. J. et al., SPIE Int. Soc Opt. Eng. 5167, 50 (2004)
[13] Park H-S. et al., Rev Sci Instrum. Characteristics of High Energy Ka and Bremsstrahlung Sources Generated by Short Pulse Petawatt Lasers (Poster E-45), Wickersham J. et al., Imaging and Proton Counting Detectors for 20- 100keV X-ray Backlighters in HEDES Petawatt Experiments (Poster E-46)
[14] Spectral Instruments Tucson, Arizona 85745 www.specinst.com
[15] J.R. Kimbrough et al., Rev. Sci Instrum. Characterization of the Series 1000 Camera system (Poster E52)
[16] Tran Vu et al., Rev Sci Instrum. Single Channel Analog Data Links for use with High Bandwidth Recording Systems for NIF (Poster G25)

Figure 1 Streak camera system Contrast Transfer Ration

Figure 2 Measured optical quantum efficiency of the backthinned KAF16800 optical device

Figure 3 Measured and Theoretical x-ray quantum efficiency for the KAF16800 x-ray device

Figure 4 Modeling show the computed paths of 100 electrons in a silicon matrix with 10keV impact energy

Figure 5 Sensitivities of each of the fundamental materials being tested

Figure 6 Spectral Instruments compact CCD head, power supply and controller

Figure 7 Comparison of a step response with and without optical link

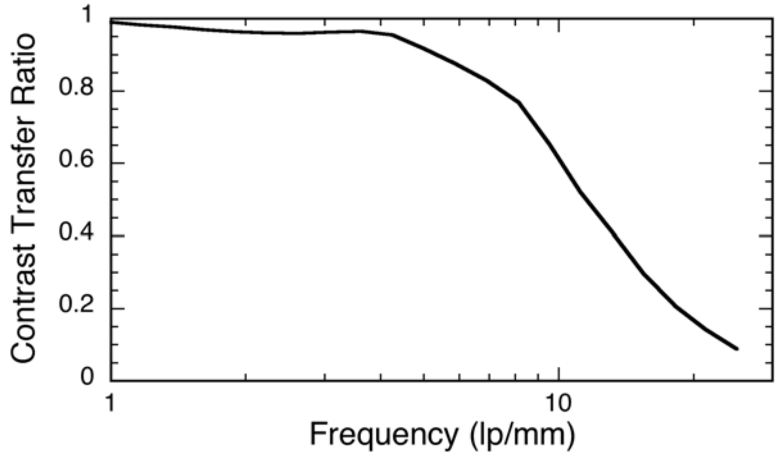

Figure 1

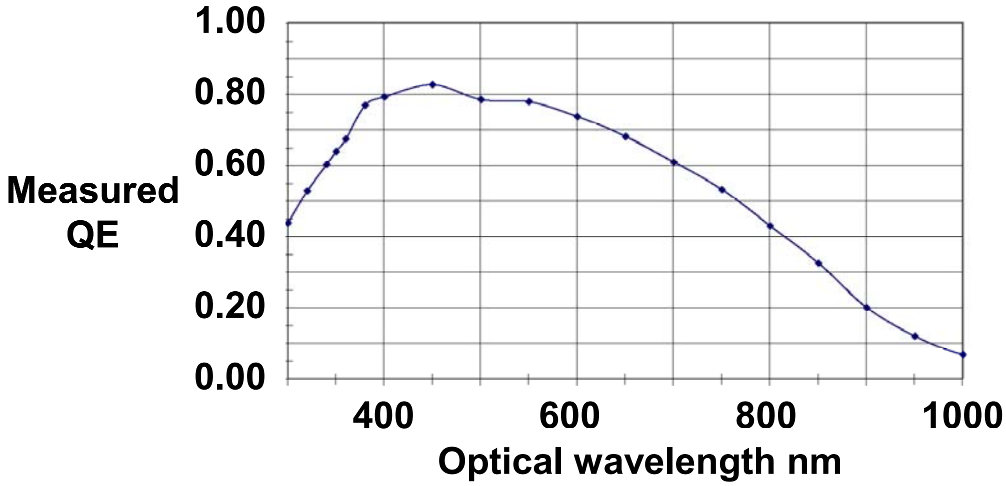

Figure 2

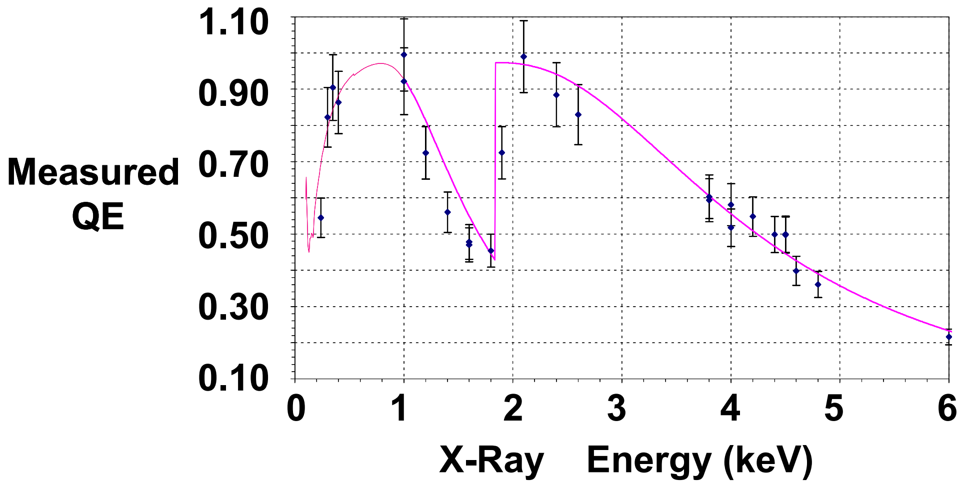

Figure 3

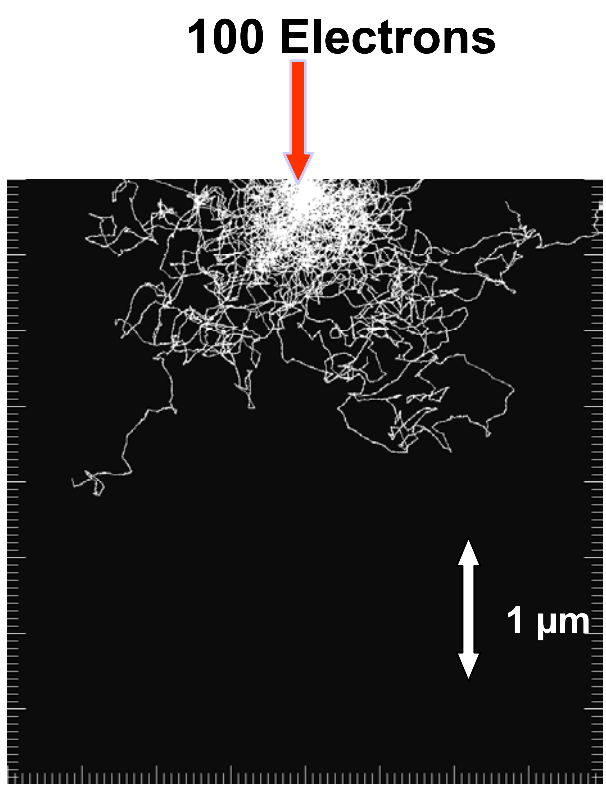

Figure 4

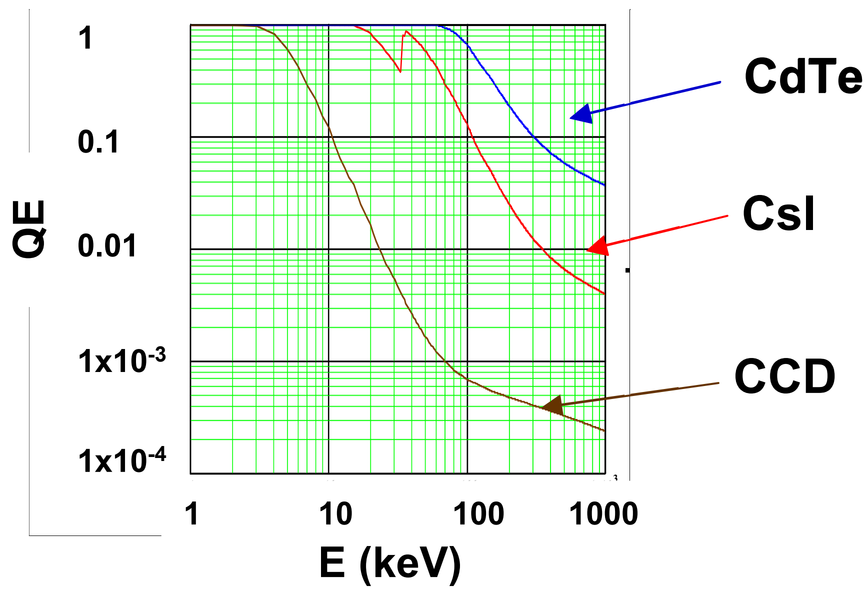

Figure 5

Figure 6

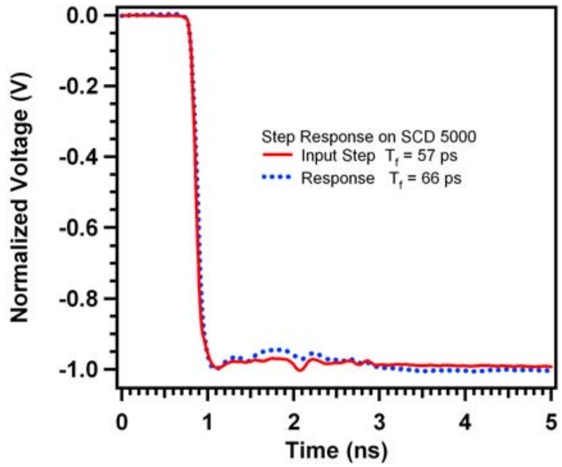
Step Response on SCD 5000
Input Step T_f = 57 ps
Response T_f = 66 ps
Normalized Voltage (V)
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
1
2
3
4
5
Time (ns)

Figure 7